BELLCOMM, INC.
1100 Seventeenth Street, N.W.   Washington, D.C. 20036

SUBJECT: Trapped Radiation Doses - Case 710

DATE: March 15, 1968

FROM: R.H. Hilberg

ABSTRACT

Space radiation doses encountered in low altitude earth orbit have become critical in the design and planning of extended missions. Dose rates have been calculated for these trapped protons as functions of shielding, orbital altitude and inclination. Some consideration is given to the problem of tradeoff between several variables affecting dose rates. Simplified tradeoff models are given, appropriate for the Saturn V workshop study.

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MEMORANDUM FOR FILE

INTRODUCTION

Space radiation doses encountered in low altitude earth orbit have become critical in the design and planning of extended missions. Most of these doses are produced by energetic protons trapped in the earth's magnetic field. Dose rates have been calculated for these trapped protons as functions of shielding, orbital altitude and inclination. The calculations show that the dose increases rapidly with altitude and that the orbital inclinations usually considered because of the latitude of the launch site are essentially worst cases. Some consideration is given to the problem of tradeoff between several variables affecting dose rates.

CALCULATIONS

While the total radiation dose accumulated will include contributions from cosmic rays and possibly solar protons, most of the dose is expected to be produced by trapped particles. Vette's tabulations of energetic proton and electron flux intensities have been used for these calculations (Reference 1). Since the electron induced dose, using the 1968 electron environment (Reference 2), is significantly less than the proton dose for shields thicker than about 0.3 g/cm^2, only proton doses are included in the results.

The dose values given are point doses evaluated for energy deposition in human tissue. The energy deposition in bone would be about 5% less, in film about 30% less. The shielding is provided by spherical shells of aluminum. Replacing the aluminum by other materials is discussed in Reference 4. Since body shielding is not included in these calculations, skin doses are approximately half of the doses given here. BFO depth doses correspond to an additional shield of 5 gm/cm^2.

The biological effectiveness of the resulting doses was included by calculating REM doses, in addition to Rad doses, based on RBE values given in Reference 5. Average values of RBE range from 1.1 - 1.4 in the cases considered here, increasing as shield thickness decreases.

RESULTS

The dependence of the dose on shield thickness is shown in Figure 1. The effectiveness of an additional increment of shielding material decreases as the overall thickness increases. This means that after the shield is increased above about 1 gram/cm^2, it is difficult to decrease the dose greatly by adding additional mass.

In orbits reaching less than about 600 nautical miles above the surface of the earth, intense flux rates are encountered only in the region known as the South Atlantic anomaly. This region is centered at about 35° S latitude and 35° W longitude. It is described in somewhat more detail in Reference 3, and is characterized by a rapid increase in average flux rate with increasing altitude. This altitude dependence is shown in Figures 3 and 4. It should be kept in mind that this dose is not a constant dose, but rather a pulsating dose, being significant only while the spacecraft is in the vicinity of the anomaly. Since the time spent in the anomaly does not change radically as the orbital inclination is increased once it has reached about 35°, the average dose rate is relatively independent of inclination for values above 30°. This is shown in Figure 5 for several altitudes. For orbital inclinations less than about 15°, there should be little dose encountered.

For the purposes of studying tradeoffs, it is convenient to consider a candidate orbit and look at the effect of varying the parameters affecting the dose. The model configuration chosen is a spacecraft with 1 g/cm^2 shield thickness in a circular orbit with altitude of 270 n.m. and inclination of 50°.* Figures 6, 7 and 8 show the dose dependence on orbital inclination, altitude and shield thickness, respectively.

For the purposes of tradeoff calculations it will be convenient to use mathematical expressions for the dose-shielding-altitude relationships. The curves in Figures 7 and 8 indicate that this is possible with at least 50% accuracy. For the altitude dependence, the expression

$$D.R. = .0178\ e^{h/67} = e^{\left(\frac{h-270}{67}\right)}$$

describes the relative dose rate dependence on altitude in the range 200-300 n.m. In this expression h is expressed in n.m. This expression corresponds to the curve for 1 g/cm^2 in a 30° orbit in Figure 7. For the dependence of relative dose rate on shield thickness, T, the expression

$$D.\ R. = T^{-.87}$$

(correspnding to the 300 n.m., 30° curve in Figure 8) gives a good fit to all of the curves.

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*The nominal orbit for the Saturn V Workshop studies.

Combining these expressions with $f(\lambda)$ given in Figure 6, the dose rate in any orbit with an arbitrary shield thickness is given by

$$D.\ R. = 0.8\ \text{rad/day}\ f(\lambda)T^{-.87}e^{\left(\frac{h-270}{67}\right)}$$

Using selected dose limits allows one to find combinations of altitude and shield thickness which will permit the allowable dose. For the example of .2 rad/day for 600 days and $\lambda=50°$, the expression

$$.2 = .8\ T^{-.87}e^{\left(\frac{h-270}{67}\right)}$$

provides the tradeoffs between T and h.

CONCLUSIONS

The calculations indicate that a spacecraft with an effective thickness of about 1 gram/cm^2 aluminum will provide sufficient protection for a man in the 200-300 n.m. region for missions of moderate length. Thinner spacecraft such as the Lunar Module will be inadequate for continuous occupation for the entirety of such a mission. For films, which may be more sensitive to particulate radiation than man, significant extra shielding may be required.

RH Hilberg

1011-RHH-cb R. H. Hilberg

Attachments
Figures 1 thru 8

REFERENCES

1. J. I. Vette, "Models of the Trapped Radiation Environment," Volume 1, NASA SP-3024, 1966.

2. J. I. Vette, A. B. Lucerno and J. A. Wright, "Models of the Trapped Radiation Environment," Volume 2, NASA SP-3024, 1966.

3. R. H. Hilberg, "Radiation Levels on AS-503 Missions - Case 340," Bellcomm Memorandum for File, July 11, 1966.

4. R. H. Hilberg, "Relative Effectiveness of Several Materials as Radiation Shields - Case 710," Bellcomm Memorandum for File, March 29, 1968

5. W. R. Langham, Ed., "Radiobiological Factors in Manned Space Flight," National Academy of Sciences, National Research Council, 1967.

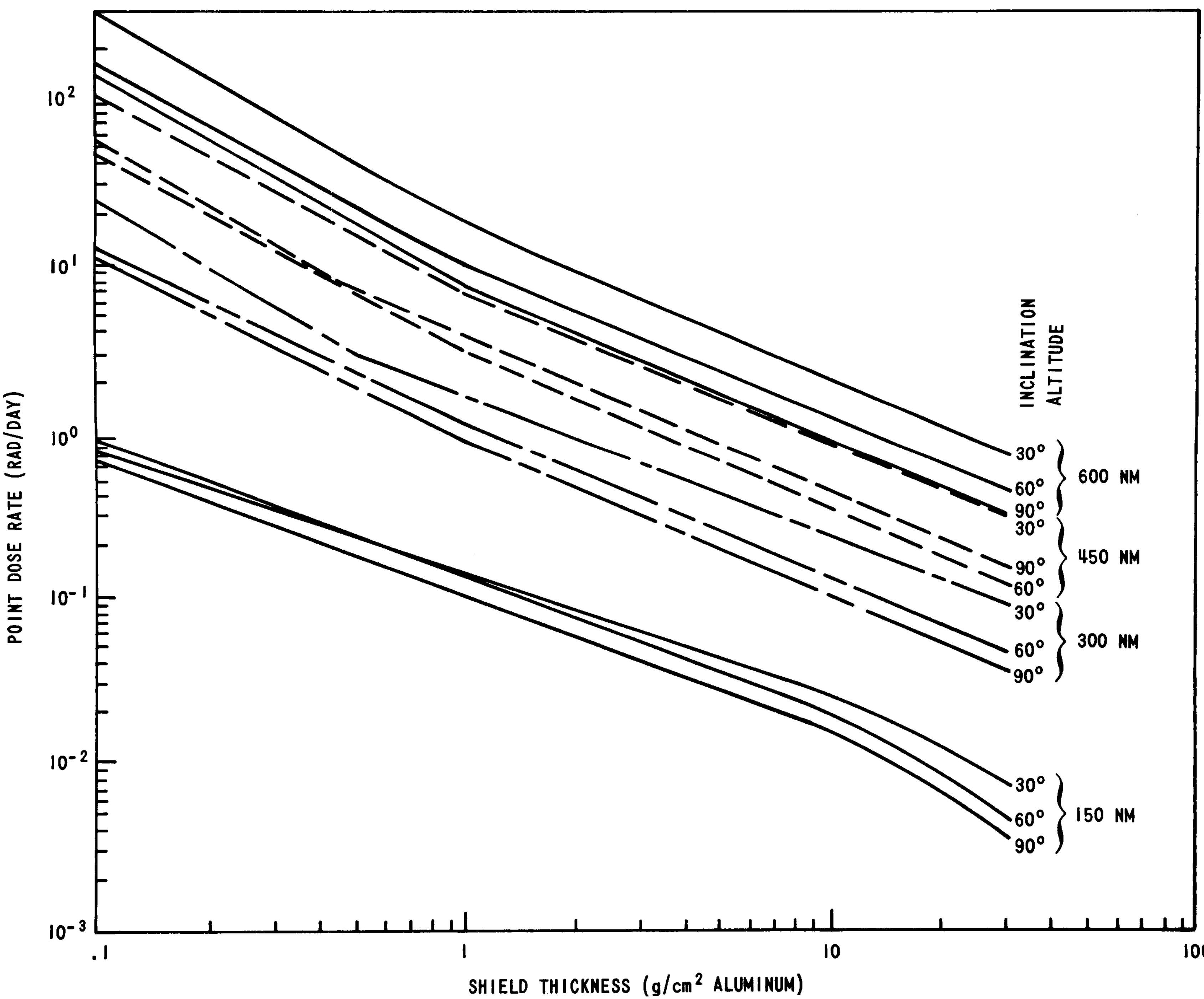

FIGURE 1 - TRAPPED PROTON DOSE RATES IN LOW EARTH ORBIT

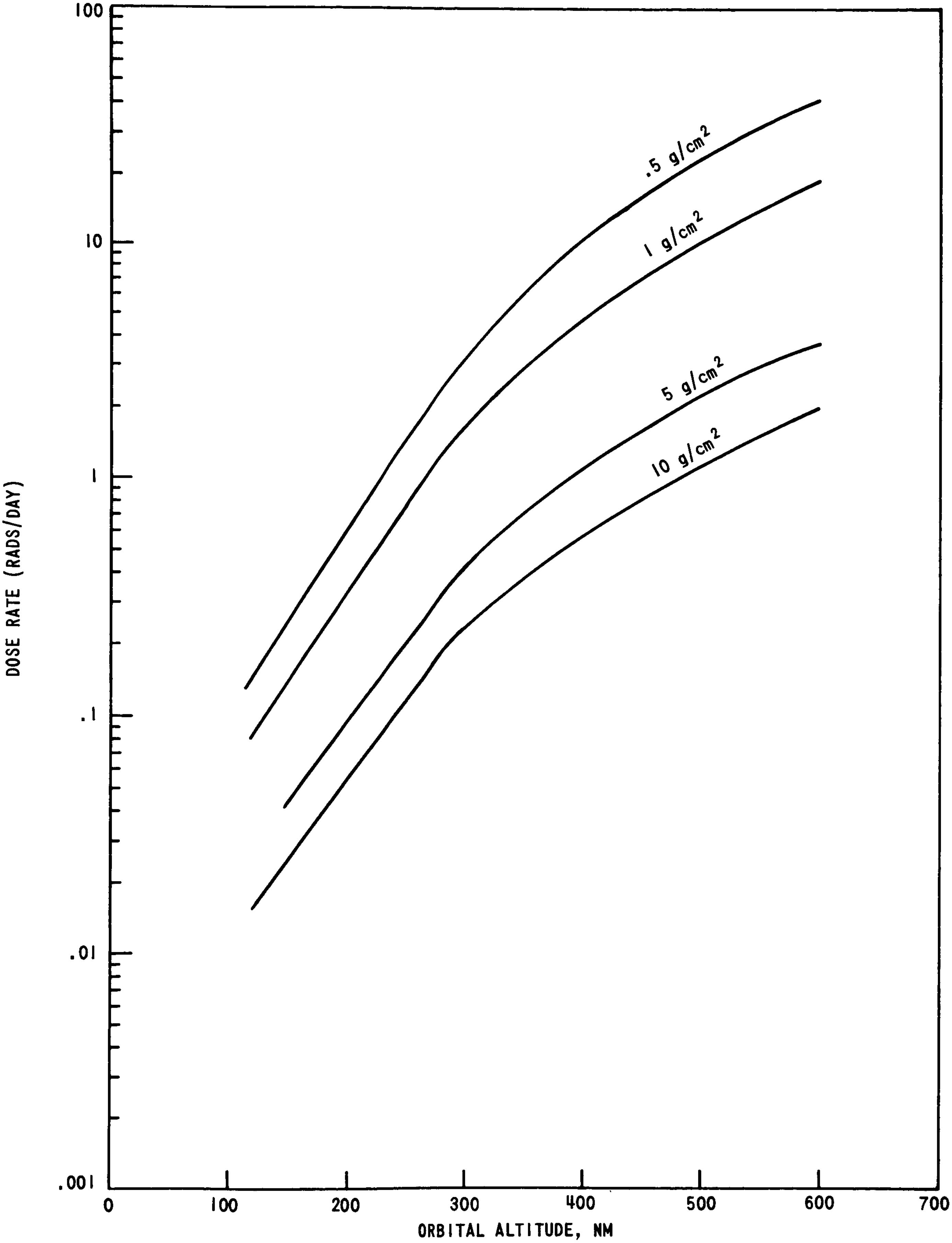

FIGURE 2 - ALTITUDE DEPENDENCE OF TRAPPED PROTON DOSES IN CIRCULAR ORBITS - 30° INCLINATION

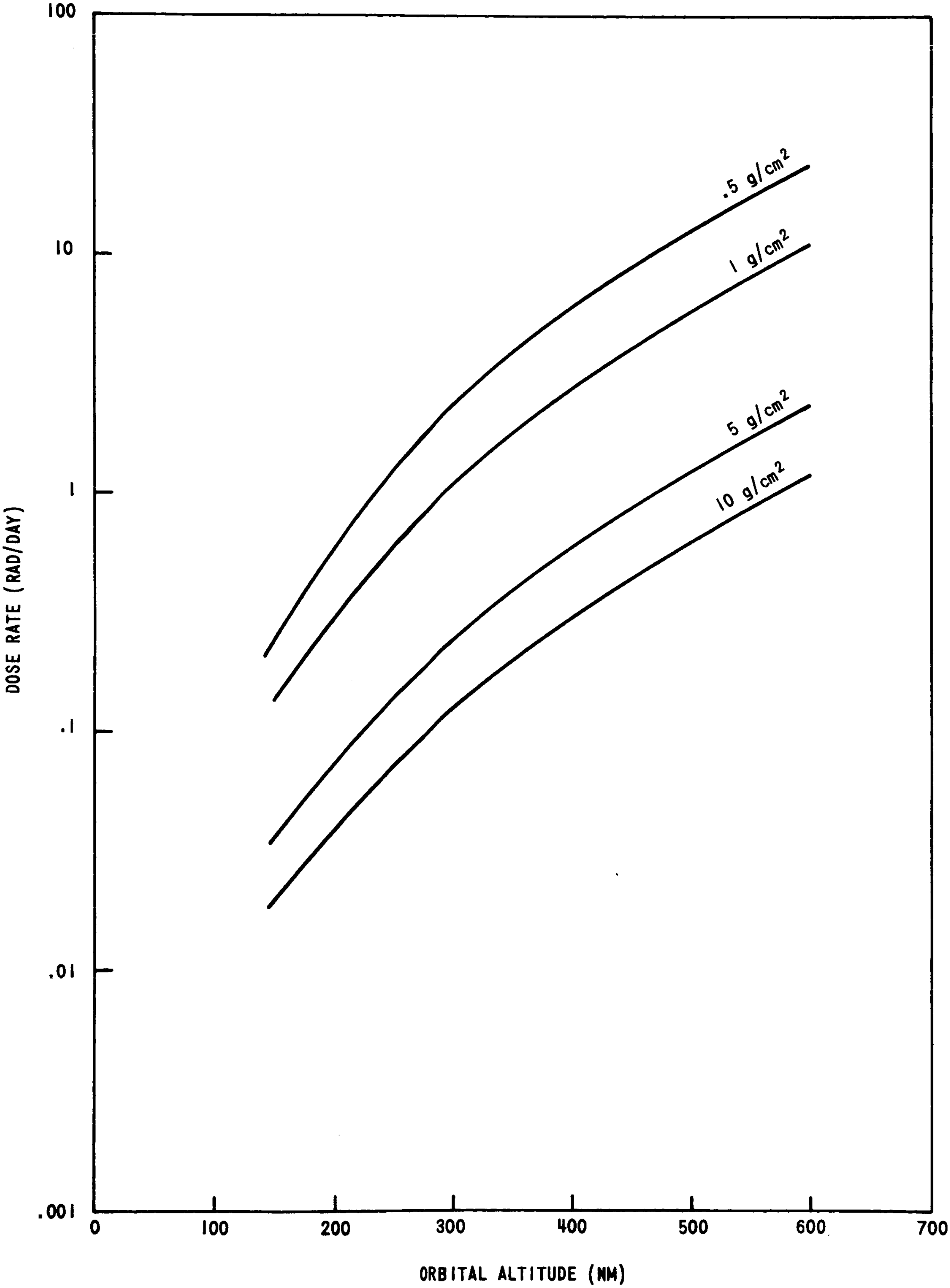

FIGURE 3 - ALTITUDE DEPENDENCE OF TRAPPED PROTON DOSES IN CIRCULAR ORBITS - 60° INCLINATION

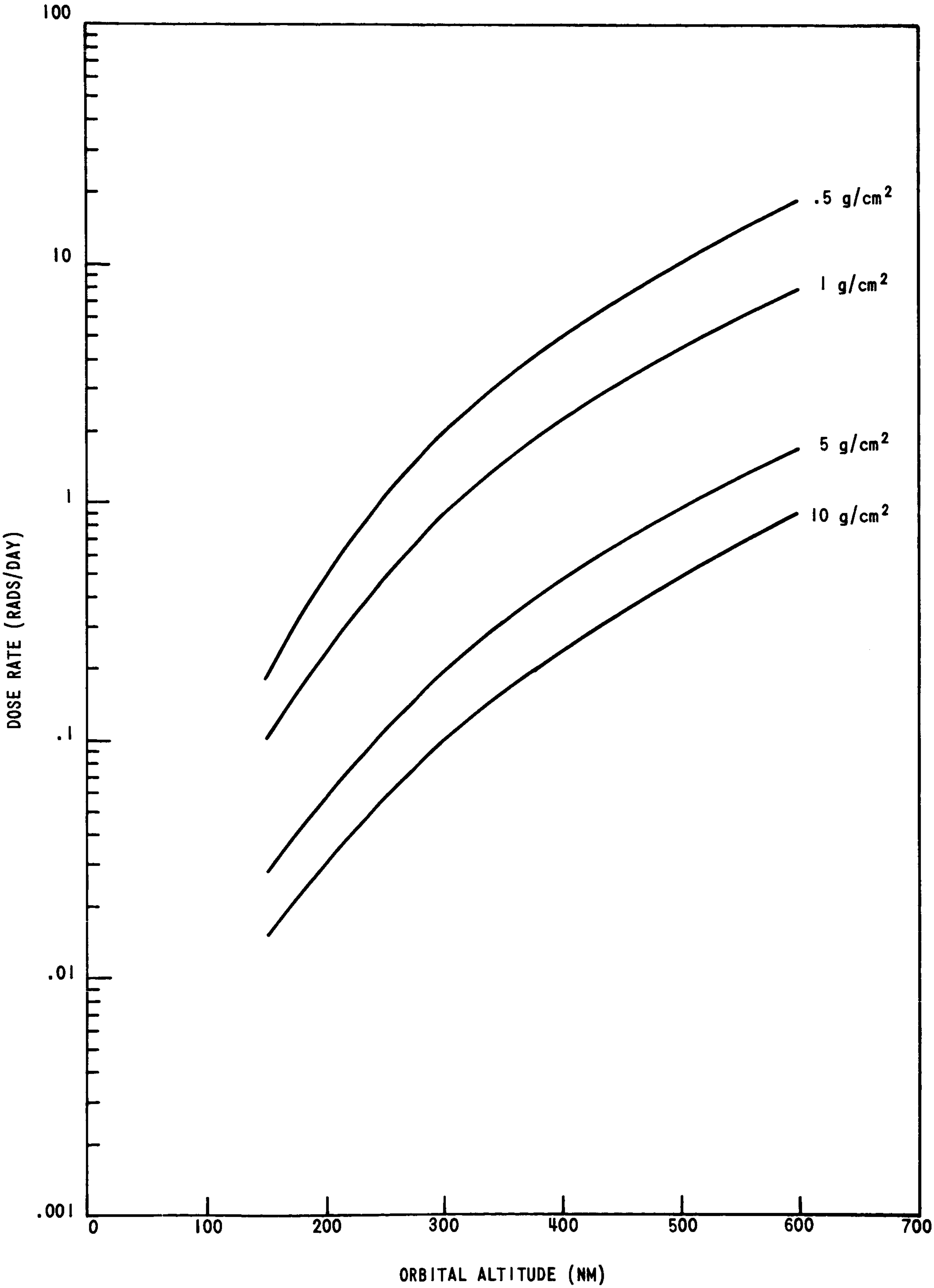

FIGURE 4 - ALTITUDE DEPENDENCE OF TRAPPED PROTON DOSES IN CIRCULAR ORBITS - 90° INCLINATION

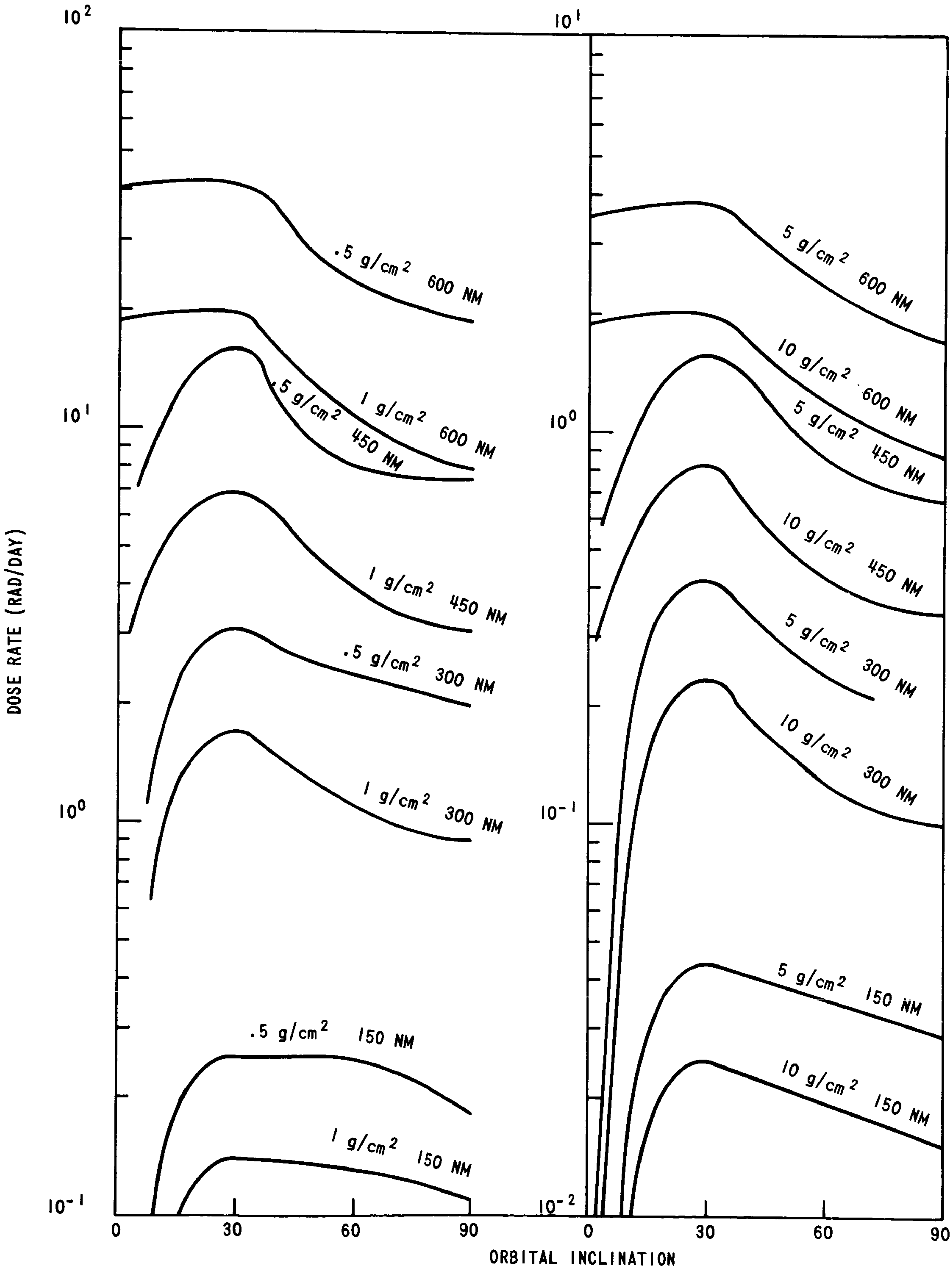

FIGURE 5 - CIRCULAR ORBIT DOSE RATE DEPENDENCE ON ORBITAL INCLINATION

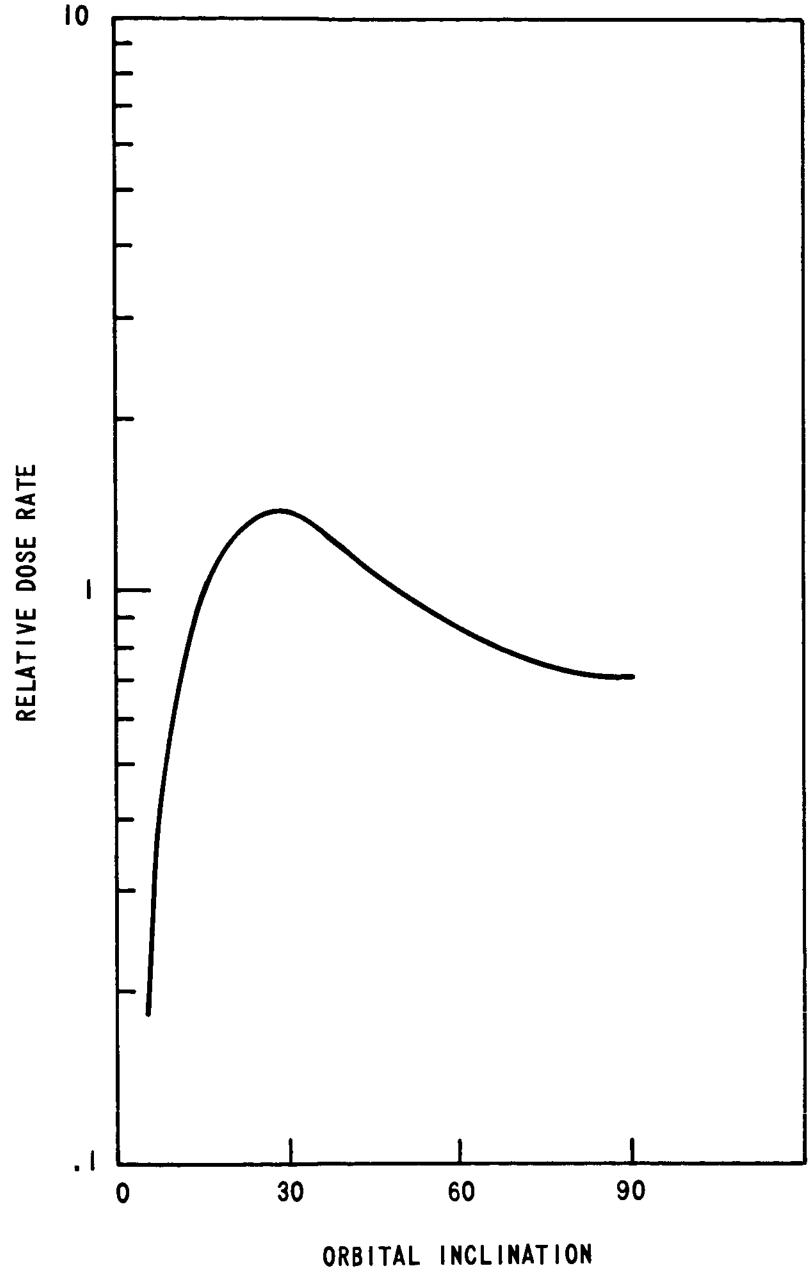

FIGURE 6 - DEPENDENCE OF TRAPPED PROTON DOSE ON ORBITAL INCLINATION. THE CURVE IS NORMALIZED TO UNITY FOR A CIRCULAR ORBIT AT 50° INCLINATION, 270 NM ALTITUDE AND WITH 1 g/cm^2 ALUMINUM SHIELDING

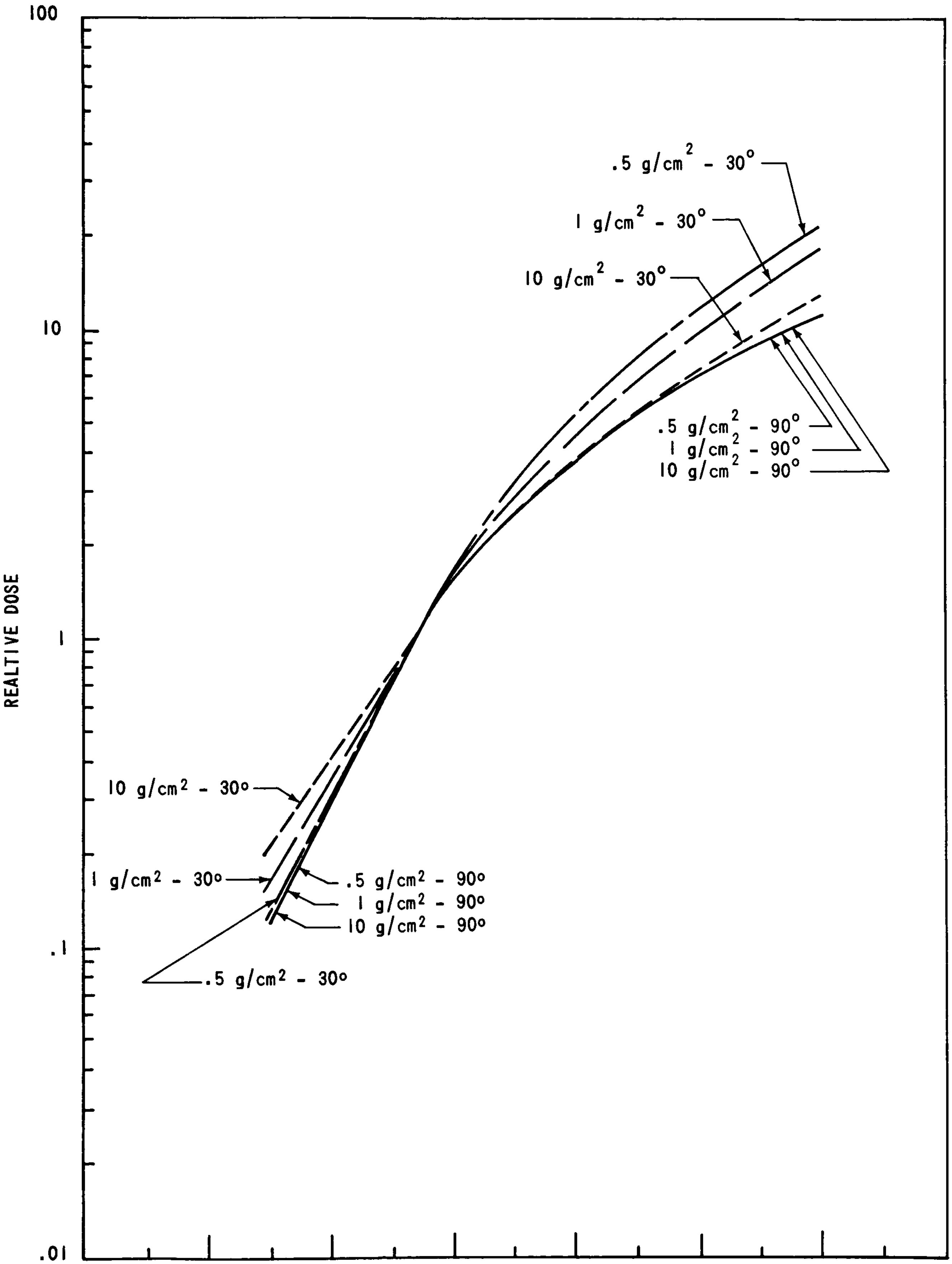

FIGURE 7 - DEPENDENCE OF TRAPPED PROTON DOSE ON ORBITAL ALTITUDE. THE CURVES ARE NORMALIZED TO UNITY FOR 270 NM ORBITAL ALTITUDE

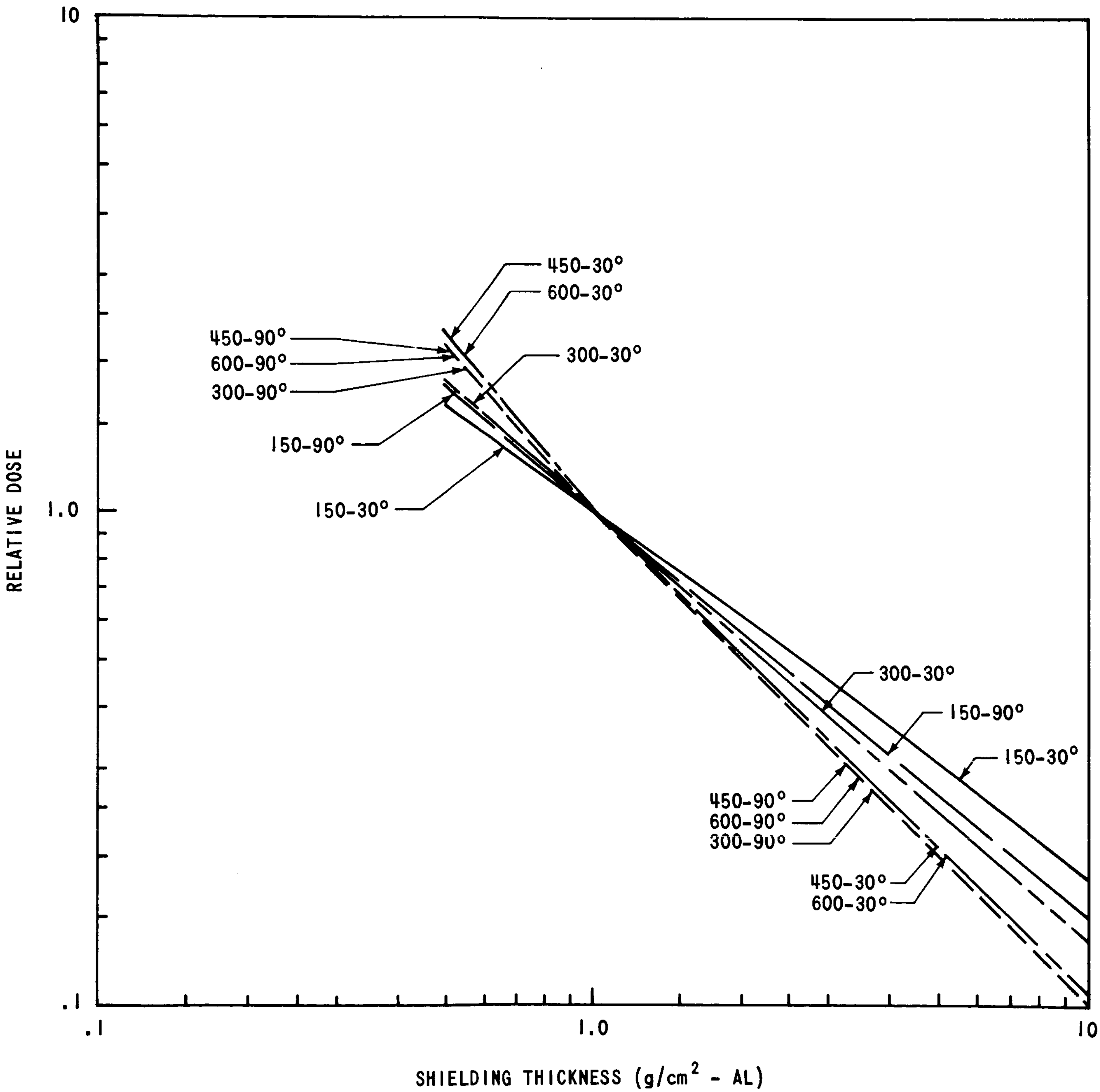

FIGURE 8 - DEPENDENCE OF TRAPPED PROTON DOSE ON SHIELD THICKNESS. THE CURVES ARE NORMALIZED TO UNITY FOR ONE GRAM PER CM^2 ALUMINUM